included angle of the viewing zone defining a distance at least 18% of the dimension of the device in the parallax direction.

As we explain in more detail below, the inventors have undertaken a detailed study into the way in which holographic elements exhibit parallax when the device is tilted and the way in which this is interrelated with image blur. The particular combination of parameters defined above has been found to lead to a new security device which solves the problems mentioned above by utilizing movement and depth to allow the device to be easily verified but in such a way that the device is difficult to counterfeit.

In the past, the use of depth has not been exploited due to a number of limitations that are also a direct consequence of the origination process. The main limiting factor has been that the greater the depth of a feature, the less visually distinct it is under less than perfect viewing conditions. That is, under less than perfect lighting a feature present in a back or forward plane will be blurred. Previously, this has been viewed as unacceptable as the detail of the feature cannot be recognised. In the current approach, the absolute clarity of the feature in the forward or backward plane is not as important as the feature's presence and/or its interplay with other elements within the security device.

One example where the technique of classical holography leverages the parallax effect to create a novel form of optical variable effect security feature is described in US-A-5694229, wherein a Moiré pattern is holographically recorded into a Benton rainbow hologram using the well-known two-step (H1-H2) transfer process. The Moiré pattern is recorded into the H1 hologram by creating an object image generated by the parallax interplay between two artwork components (e.g. transmission masks) located one behind the other and separated by a few millimetres. The artwork components illustrated within the inventive teaching being in each case a concentric periodic

two sticks is significantly greater than their width. If you next move your head to the right or left so as to change your direction of observation (i.e. line of sight) then you see that the sticks appear to change their relative positions. This is made evident by the observation that the rear stick first moves out of alignment with the front stick, thereby becoming visible, and then appears to move away from the front stick (i.e. they mutually displace) with the mutual displacement being proportional to the angular change in viewing position.

It should be noted that the rate of mutual/relative displacement of the sticks with changing viewing position or angle is proportional to the separation between the sticks, i.e. the bigger the separation between the sticks the more rapidly they appear to "move apart" (or mutually displace) as viewing position moves away from the central "in-line" viewing position.

Specifically we observe that moving the viewing position to the right causes the rear stick to move or displace (in a relative sense) to the right and conversely causes the front stick to appear to move to the left. Clearly, movement of the viewing position to the left causes a reversal of the above.

Therefore, in summary, we see that these parallax related displacement effects allow an observer to judge both the relative distance between two objects from him and also which of the two objects is closer. If we further recognise that parallax information can equally well be used to make visual judgements about the relative distances of two points on a 3-dimensional object from the observer, we can readily appreciate the importance of parallax to the perception of depth, distance and 3-dimensionality in our everyday life — which is why the human brain has evolved to continuously and subconsciously evaluate parallax

hologram and intaglio overprint or other non-diffractive features (again their positional invariance gives them a role as a "datum")

As will be clear, this invention relates to surface relief microstructures and should be contrasted with volume holograms.

<u>Quantifying Parallax motion in the hologram:</u>

Following on from this introduction to the concept of parallax using two aligned sticks, Figure 1 shows two holographic image elements (shown as arrows) 1,2 located on front and rear layers or planes a distance LD apart. These are to be viewed through a rectangular viewing aperture 3 of length SL (akin to a Benton rainbow slit) a distance F away.

As discussed earlier as the observer moves away from a centre viewing position (CV) the sticks 1,2 misalign due to effect of parallax displacement. Now for simplicity we assume that the front layer is coincident with the surface layer of the microstructure generating the hologram and remains unchanged in position and we therefore obtain the three views represented below the viewing aperture in Figure 1.

Now the total parallax displacement (PD) of the rear arrow 1 between the extreme right hand view (RV) and the extreme left hand (LV) is given by:

$$PD = XR' + XL'$$

However

$$XR' = XL' = XR \text{ cosine } (PhiMax) = LD * \text{tangent } (PhiMax) * \cos(PhiMax)$$
$$= LD * \sin(PhiMax)$$

Hence

$$PD = 2 * LD * \sin(PhiMAX)$$

where PhiMax = the uninterrupted viewing angle, either side of the surface normal and with reference to Figure 1 we see that

$$\sin(\text{PhiMax}) = SL/2\ (\text{SQRT}\ [(F + LD)^2 + SL^2/4) \approx SL/2F * \text{SQRT}\ [1 + (SL/2F)^2]$$

since F is typically >> LD)

Now although we have considered a very simplified geometry this result remains true for all cases. In particular we have made the convenient assumption that the front layer is coincident with the microstructure surface plane. However, the above result also quantifies the parallax displacement when the first arrow forms an image in front of the surface plane.

A comparison of the amount of parallax displacement recorded in to the rear plane of existing banknote holograms, with that present in a typical 2D/3D hologram used in cards, and with that present in devices according to the invention shows the following:

Existing banknote holograms provided in a few micron thick embossed film on flexible micro-rough banknote paper: depth/distance between layers 2mm; viewing angle 22 degrees; Parallax displacement 0.8mm (i.e. minimal).

Typical non banknote holograms i.e. Cards etc usually provided either as a few micron(s) thick film, on smooth and rigid substrates (cards); or, as self supporting 25-50 micron film (i.e. label) on smooth or micro-rough surfaces (foil dimensions less than 30mm x 30mm): depth/distance between layers 2-6mm; viewing angle 22-40 degrees; Parallax displacement 0.8mm to 4.5 mm.

Typical devices according to the invention: depth 6,8,10 mm; viewing angle for 6mm sample @ 45 degrees giving parallax displacement of 5mm; viewing angle for 8 & 10mm samples @ 38- 40 degrees giving parallax displacements of 5.8 & 7.2 mm respectively.

Rate of Parallax Displacement

One of the most noticeable differences between the depth samples recorded at 10mm and 6mm was not so much the total extent of parallax movement but rather the rate or speed of movement on twisting the substrate or changing angular viewing position along the axis of parallax.

If we define the rate of parallax displacement PV as PV = Total Parallax Displacement/(Total viewing angle) with the viewing angle expressed in radians. It then follows that

$$PV = PD/(2*PhiMax) = 2*LD * \sin (PhiMax)/(2*PhiMax)$$

Thus when expressed in radians the rate of parallax movement per radian equals the distance between the interacting planes or layers.

Depth-related Image Blur

The biggest inherent drawback of surface relief, or embossed holography, as a visual medium, is the degree of chromatic aberration and blurring of the image that takes place under non-point source polychromatic (i.e. white light) illumination.

Image plane rainbow holography (invented by Benton) sought to limit chromatic aberration by sacrificing vertical parallax i.e. no vertical depth related vertical parallax effects are permitted - the benefit being a great reduction in chromatic aberration. This is illustrated in Figures 2A-2C, which show the replay characteristics of the rainbow hologram in perspective, plan and side view respectively.

In particular, we see that the light of a particular colour is replayed into a horizontal viewing zone or "slit" and should the observer alter his viewing position along the horizontal axis then he will see horizontal parallax and perspective effects. Conversely altering his viewing position in the vertical axis will cause him to see a

rainbow progression of viewing slits - and therefore a particular image element, the same parallax effects in a progression of rainbow colours. However, there remains significant blurring of those image elements located more than a few millimetres from the surface plane. Now, to qualify the relationship between depth and blurring, the inventors recognised the need to recognise the optical consequences of the fact that all image elements are

patch are 22mm x 22mm which is a typical hologram/OVD size for banknote application. The dimensions of the image or symbol are around 3mm in the moving direction (east-west).

If we next assume this hologram has a viewing angle 2*PhiMAX of 40 degrees - which is very typical of a Benton Rainbow Hologram, then applying the formulae derived for parallax displacement and blur to a range of depths D = LD = 2,4,6,8mm we arrive at the results which are summarised in Figures 9 and 10 showing appearances at actual size.

Referring first to Figure 9, this shows the apparent location of the depth image in the three pertinent views left, centre and right, whilst viewed under point source lighting at the range of depths described above. The key point to note is that for the typical holographic replay angle used in this simulation, clear and recognisable parallax or depth movement only occurs at depths of 6mm and above in the sense that:

within each of the three views the centre of gravity of the image has clearly shifted with respect to the left and right hand boundaries of the device - which function as positional datums.

We also note that the parallax displacement PD in the 6mm case equals 4.1mm which as a fraction of the image width is 18.6%.

Finally we note that the parallax movement in the 6mm deep image is some 150% of the chosen symbol/image width of 3mm. We shall comment on the significance of the symbol width and type next.

Consider next Figure 10 which shows the same image arrangement and matrix of depths, this time illuminated by a 0.75m linear light source. We have endeavoured to simulate the smear effect by displacing and overlaying a copy of the central image by +/- 0.5 S. As expected the smear or blur becomes visually significant at 4mm and above, however because of the shape and graphical form of the image its essence is still recognisable at the desired minimum depth of 6mm. Specifically the average smear S

forms a virtual image depth D =LD behind the resist surface. Thus in the focal configuration shown, the front layer will be positionally invariant whereas the rear layer will through its apparent displacement relative to the surface plane features provide the psycho-optical perception of depth.

The first parallax parameter we wish to encode into the holographic OVD, is the rate of parallax movement per radian PV. If the two image elements which are providing the relative parallax effect or displacement are the two artwork transmission masks 20,21 shown in Figures 13,14, then we know from earlier theory that the inter-planar separation between masks LD should be made numerically equal to the required displacement rate PV.

For example should the required rate of motion be 6mm per radian then the spacing LD between transmission masks should be set at 6mm.

Having configured the Holographic set-up to have the required inter-planar separation LD we next need to adjust the recording geometry to set PhiMax at an appropriate value in accordance with the additional preferred design rules. Namely that:

- the parallax displacement PD should be not less than 20% of the effective width of the OVD in the "moving" direction
- the parallax displacement PD should be greater or equal to the width of at least one of the moving symbols (preferably the width of the symbol with the smaller dimension)
- the illumination averaged blur or smear S should not exceed the width of the moving symbol.

Now having experimentally set the rate of movement PV, we find it convenient to recall that:

$$PD/LD = 2*\sin(PhiMax) = PD/PV,$$

where the final expression assumes we tolerate the approximation PV ≈ LD for values of PhiMax less than 0.5 radians

and similarly that

S/PD = <LF> * VP(Phi=0) * [D*tan (PhiMax)/LD*sin (PhiMax)]
= <LF> * VP(Phi=0) * [D/LD]/cos (PhiMax)

which for PhiMax less than 0.5 radians gives cos (PhiMax) ≈ 1.0 and therefore the simplification

S/PD ≈ <LF> * VP(Phi=0) * [D/LD]

Where the "vee" brackets around LF indicates that we take its value averaged over the spectrum of illumination conditions.

Assume an average value LF as the arithmetic mean of the practical point source LF (=0.1) and the worst case extended linear source LF (=1), which =0.55.

Therefore since the value of VP at (Phi =0) is 1.0, the above simplifies to

S / PD =0 .55 * D / LD

Suppose, in scenario A, we select as our design choice a symbol of 3mm dimension which we further choose to be located at 6mm behind the surface plane; the other elements which it interacts with being located on the surface plane. Hence D=LD=6mm. Now as we require S to be less than 3mm it therefore follows in scenario A that the parallax displacement must be less than 3/0.55 or 5.45mm.

To more precisely specify the required level of movement PD we next invoke the second requirement, namely that PD must not be less than 18% of the effective width of the device which as part of scenario A we suppose to be 22 mm. This then requires the parallax motion PD to lie within 5.45mm and 4.4mm. What value within this band was

chosen for PD would depend on whether movement or "symbol delineation" under linear light sources was of greater importance to the holographic or OVD designer.

Suppose it was the latter and we chose PD to have a value of 4.4mm, then it follows that sin(PhiMax) = 4.4/(2*6) = 0.366. Therefore to provide the desired viewing (half) angle PhiMax within the recording geometry of Figure 13, we locate masks at either end of the H1 recording slit such that its length

$$SL \equiv \text{tangent}(PhiMax)*2*F$$

Supposing F to be 250mm then this sets a value for SL of 183mm.

However, for a scenario B, suppose the effective width of the OVD is defined to be 35mm, thereby giving a minimum level of movement PD of 7mm. Now we know from above, if only one of the interacting elements or symbols has been

7mm of movement is given by sin (PhiMax) now equals 7 /(2*6) or 0.58 - hence the slit length SL which is the result of the calculation 250*2*tangent(PhiMax) = 355mm.

Reducing Depth Blur through interrupted or modulated Parallax motion

We have seen in Figures 3 and 4, how the blur in an embossed hologram or OVD is determined by the effective microstructure "footprint" generated at the diffractive interface (i.e. the photo-resist surface during the H2 recording process and the embossed lacquer/reflective coating interface in the final foil device).

Specifically the "footprint" generated by any point on the holographic image is proportional to the product of the uninterrupted total viewing angle and distance of the holographic image behind or in front of the surface plane. The replay characteristics of such an OVD providing uninterrupted or unmodified parallax motion in the horizontal axis is shown in Figure 16. In this context we mean parallax motion in which the "moving image(s)", when they are not passing behind or being eclipsed by other image elements appear with essentially unmodified brightness or colour over their entire parallax viewing zone and also move with a constant rate PV (expressed here in mm per radian).

However the inventors recognised that if the total angular viewing zone is segmented by recording or creating a surface relief structure which significantly modifies or modulates the visible brightness or colour of the moving image(s) as it is observed across its parallax movement then it is possible to radically alter the relationship between holographic image depth and the attendant blur or smear due to non point source lighting.

Consider Figures 17 and 18 which show plan and perspective views of a first embodiment of this concept of interrupted or modified parallax motion, wherein a holographic "depth" image is shown replaying into N (=5)

CLAIMS

1. A security device comprising a surface relief microstructure which, in response to incident radiation, replays a hologram viewable within a viewing zone, the hologram comprising at least a first, holographic image element in an image plane spaced from the surface of the microstructure, the device exhibiting at least one further image in a plane spaced from said image plane of the first holographic element, wherein the spacing between the first holographic element image plane and the plane of the further image is such that, on tilting the device, the first holographic image element exhibits apparent movement relative to the further image, the rate of movement being at least 6mm per radian of tilt, and the product of the rate of movement and the included angle of the viewing zone defining a distance at least 18% of the dimension of the device in the parallax direction.

2. A device according to claim 1, wherein the at least one further image is substantially spatially invariant relative to the device.

3. A device according to claim 2, wherein movement of the first holographic image element causes the first holographic image element to overlap the, or one of the, further images.

4. A device according to claim 2 or claim 3, wherein the at least one further image is non-holographic.

5. A device according to claim 1 or claim 2, wherein the hologram defines the at least one further image as one or more second holographic image elements.

6. A device according to any of the preceding claims, wherein the plane of the further image(s) is substantially coincident with the plane of the surface relief microstructure.

7. A device according to at least claim 5, wherein the first and second holographic image elements are formed in planes respectively in front of and behind the plane of the surface relief microstructure.

8. A device according to any of the preceding claims, wherein the surface relief microstructure replays the first and/or second holographic element into a set of discrete, angularly spaced subsidiary viewing zones.

9. A device according to claim 8, wherein the or each element is not visible in spaces between the subsidiary viewing zones.

10. A device according to claim 8 or claim 9, wherein the subsidiary viewing zones are substantially equally spaced apart.

11. A device according to claim 9 or claim 10, wherein the viewing zones and the spaces between the viewing zones have substantially the same angular extent.

12. A device according to any of the preceding claims, wherein the first and/or second holographic image elements have a dimension of at least 3mm in the parallax direction.

13. A device according to any of the preceding claims, wherein the or at least one of the holographic image elements exhibits a colour variation as it moves.

14. A device according to any of the preceding claims, wherein the first holographic image element defines a symbol.

15. A device according to any of the preceding claims, wherein the at least one further image defines a symbol.

16. A device according to claim 14 or 15, wherein the or each symbol comprises a shape having a visual meaning, association or resonance with an observer.

17. A device according to any of the preceding claims, wherein the first holographic image and the at least one further image are relatively movable to form a recognisable symbol.

18. A device according to any of the preceding claims, wherein the product of the rate of movement and the

included angle of the viewing zone defines a distance at least 18.6% of the dimension of the device in the parallax direction.

19. A device according to any of the preceding claims, wherein the included angle of the viewing zone is no greater than 1 radian and the size of the device in the parallax direction is less than 5 times the interplane distance.

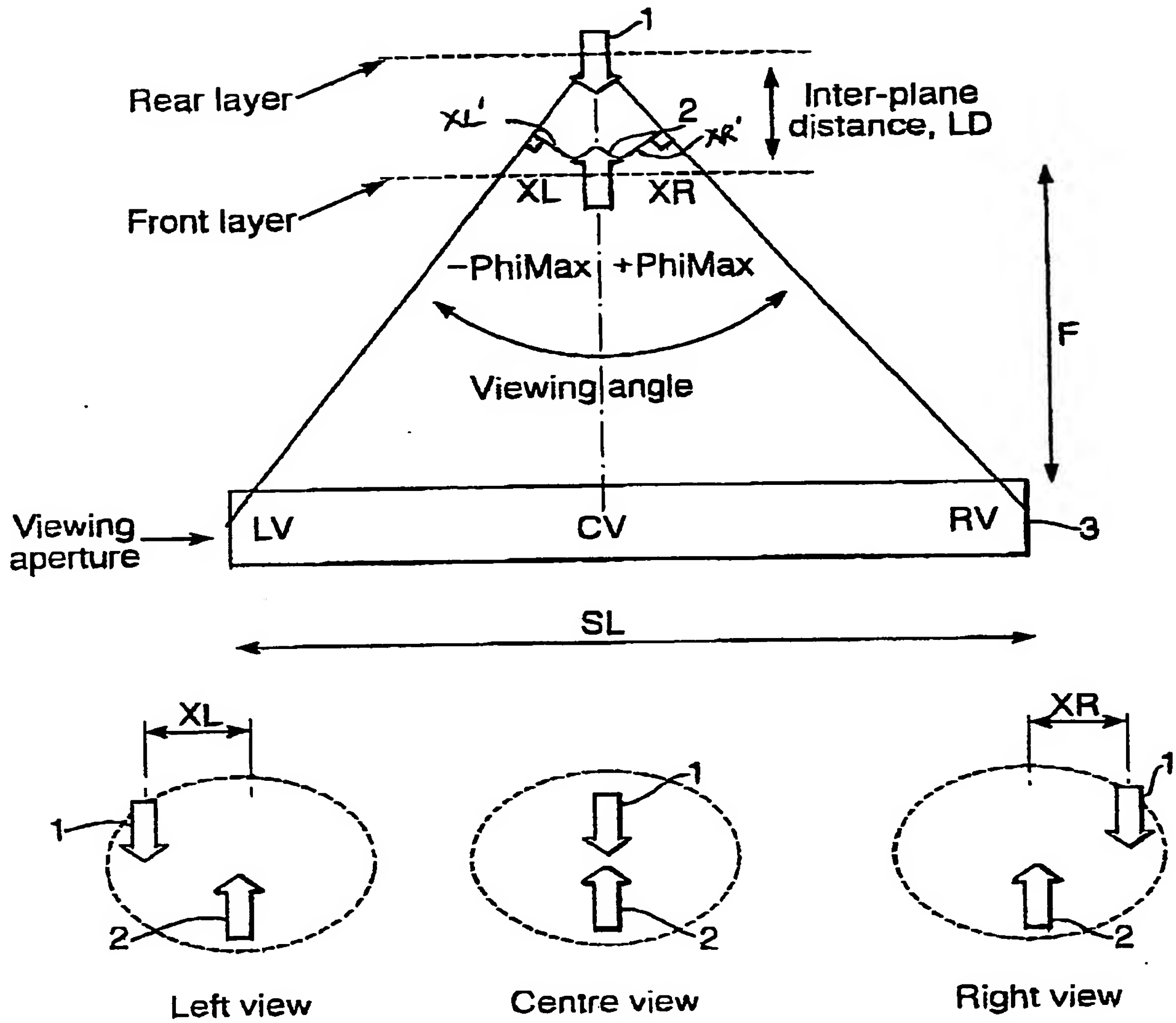
20. An article carrying a security device according to any of the preceding claims.

21. An article according to claim 20, wherein the article comprises paper.

22. An article according to claim 20 or claim 21, wherein the article comprises a banknote.

23. An article according to claim 20 or claim 21, wherein the article comprises one of a cheque, voucher, certificate of authenticity, stamp, brand protection article, or fiscal stamp.

Fig.1.


1
Rear layer
Inter-plane distance, LD
XL'
2
XR'
XL
XR
Front layer
−PhiMax
+PhiMax
F
Viewing angle
Viewing aperture
LV
CV
RV
3
SL
XL
XR
1
1
1
2
2
2
Left view
Centre view
Right view